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Investigation of Possible Usage of Electric Arc Furnace Dust in Cement Industry

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Abstract
Synopsis-In this research, possible usage of EAF dust on cement is investigated. Therefore, effects of addition of different percentages of EAF dust on the most important properties of cement such as hydration heat, water coefficient, viscosity, initial and final setting times, strength development and leachability of heavy metals were studied. Results showed that EAF dust alters the characteristics of cement unfavorably. So, it cannot be used for construction purposes. However, a prior soaking of EAF dust in water eliminates alkaline compounds which causes unfavorable alternation of cement characteristics and hence, engineering properties of the mixtures enhance especially long term strength of hardened mixtures. Leaching tests also proved that heavy metals contents of the leachates are considerably below the nonhazardous leachates limits. The above results document the perspectives of soaked EAFD solidification, disposal and the use of this waste material as a new additive to building materials.

Keywords: Electric Arc Furnace Dust, Cement, Recycling, Solidification.

1- Introduction
Electric Arc Furnace Dust (hereafter referred to as EAFD) is produced in the course of steel making in large quantities as a by-product of Electric Arc Furnace. In many countries, EAFD causes problems for storage, handling and environmental pollution. Therefore, it is mainly land filled [1)]. The aim of this research is to study the effects of addition of EAFD to cement and to encourage cement producers to use EAFD as a reliable source for cement production. EAFD composition mainly consists of Fe oxides. Unlike many other steel products, composition of EAFD in Mobarakeh Steel Company (the focus of the present work) is almost unique; as the main raw materials used in this company is DRI (70-80%). Moreover, EAFD of Mobarakeh Steel Company contains lower amounts of heavy metals (in particular Zn and Pb) compared to EAFD compositions reported in other companies[2–7)]. This difference is due to the fact that very low amount of scrap is used. Many studies about EAF dust deal with elimination of heavy metals from dust and recycling its residue in metallurgical processes [2)]. Others focus on land filling, i.e. chemical fixation of the dust by addition of Portland cement and evaluation of the toxicity of the pastes [3–7)]. The present work deals with the properties of materials prepared from Portland cements, and EAFD from Mobarakeh Steel Company.

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2- Materials and methods
The EAF dust for the experiments was obtained from Mobarakeh Steel Company. It was from the gas collector in bag filter precipitator after its condensation. The composition of typical dust is given in Table 1.
The mixtures of cement and dust were formed by using standard Portland cement which was produced in Isfahan Cement Plant. The composition of the cement is given in Table 2.
The elemination of alkaline compounds was also investigated by prior soaking of the dust in water. This process and subsequent filtering and dehydration, lightened EAFD by 20 percent (hereafter referred to as SFDD). Table 3 shows the composition of SFD dust.
For the preparation of EAFD-cement and SFDD-cement mixtures, SFDD or EAFD was mechanically mixed and completely homogenized with Portland cement. Then, by using a mixer, the pastes with a required water coefficient w = mass of water/ (mass of cement + dust) were formed. For complete comparison, 3 sets of experiments were performed: 1- EAF dust + cement; 2- SFD dust + cement; 3- Portland cement as comparative group. The dust content of the first category ranged from 0 to 3 percent. For the second group, it ranged from 0 up to 20 percent. Depending on the rheological properties

Table 1. Chemical composition of EAFD used in experiments

Chemical Composition	Fe_{tot}	Fe metal.	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	ZnO	C	S	Pb
wt. (%)	51.3	0.77	2.5	0.52	8.5	2.18	11.2	3.6	9.4	1.54	0.33	0.028

Table 2. Chemical composition of standard cement used in experiments

Composition	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	SO_3	K_2O+Na_2O	Others
wt. (%)	63	20	6	3	1.5	2	1	1

Table 3. Chemical composition of SFD dust

Chemical Composition	Fe_{tot}	Fe_{metal}	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	C	S	ZnO
wt. (%)	62.7	0.74	2.9	0.77	3.4	1.47	1.3	0.4	1.68	0.41	13.8

of the pastes, water coefficient of the mixtures varied from0.27 to 0.38.

Rheological properties of the mixtures were studied by a rotary viscometer and measuring viscosity of mixtures (cement and SFDD) and flow limits. Compressive strength of mixtures was measured by testing cubic pieces of 2 cm × 2 cm × 2 cm dimensions within the period of one week to one year. They were first kept for 24 hours at 20°C in moist air (95%) then, they were stored in water for 28 days and finally they were maintained in air (30% humidity) [5,6,8)]. The morphology of dust particles was examined by SEM on the splits obtained from the destructive tests. They were also used to investigate the composition of the hardened mixtures by X-ray analysis and an energy dispersive X-ray spectrometer (EDX). Leaching tests consisted of one day leaching of the sample with water after 28-days of hydration. In this procedure, the ratio of solid phase to water was 1:10 and 5 to 10 revolutions of the vessel made of an inert material [5,6,8)]. The content of heavy metals in the filtrate of the leachate was determined by atomic absorption spectroscopy.

3- Results and discussion

Morphology of EAF dust is shown in Fig. 1. EAF dust particles have mainly a spherical shape. X-ray diffraction analysis shows the dominant component of dust is magnetite (Fe_3O_4), with smaller amount of Periclase, Zincite, Franklinite ($ZnFe_2O_4$) and Calcium Aluminum Silicate ($CaAl_2SiO_6$) (Fig. 2).

Addition of a small amount (1% or more) of EAFD to cement changes the final setting time of the mixture dramatically; unlike cement and its mixture with SFD, initial and final setting times of cement with 2 and 3 percent EAFD happened spontaneously within about 5 minutes (not shown in fig. 3).

Fig. 3 shows setting times of mixtures of SFD dust with Portland cement. As shown in this figure, addition of SFD dust to cement decreases the initial and final setting times slightly.

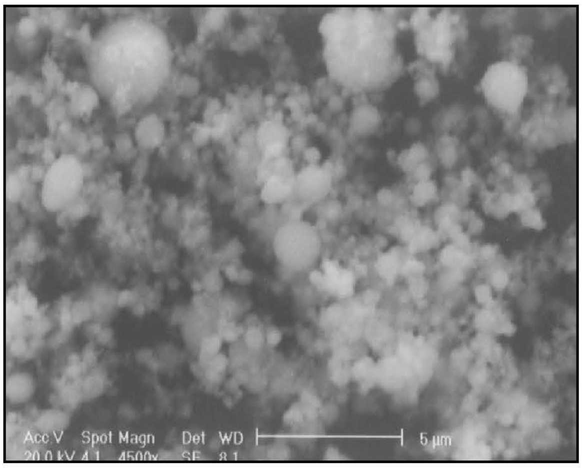

Fig. 1. Particles and clusters of EAF dust from Mobarakeh Steel Company

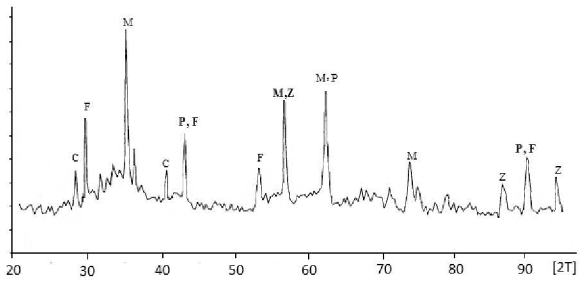

Fig. 2. X-ray diffraction pattern of Mobarakeh EAF dust , M; Magnetite, P; Periclase, Z; Zincite, F; Franklinite, C; Calcium Aluminum Silicate

Addition of EAF dust to cement increases hydration heat of the mixtures considerably (Fig. 4). In the case of SFD dust, results were in the same range with comparative group. However, slight changes were detected when SFD dust increased up to 20 percent.

Because of outrange changes in initial and final setting times and hydration heat of the mixtures regarding cement standards [9)], mixtures of cement and EAF dust cannot be used for construction purposes. Therefore, EAF dust was not used for more experiments and the remaining tests were carried out only with SFD dust.

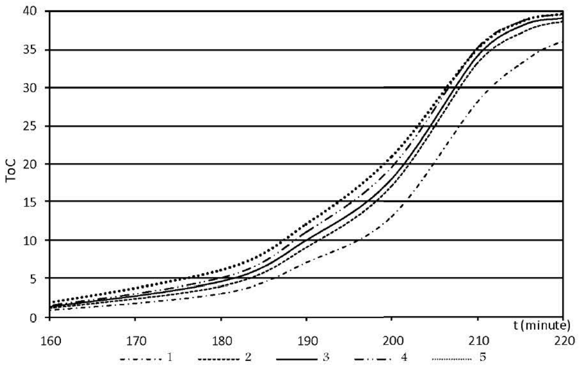

Fig. 3. Initial and final setting times of cement and mixtures. (1=cement, 2=cement+5%SFD, 3=cement+10%SFD, 4= cement+15%SFD, 5=cement+20%SFD)

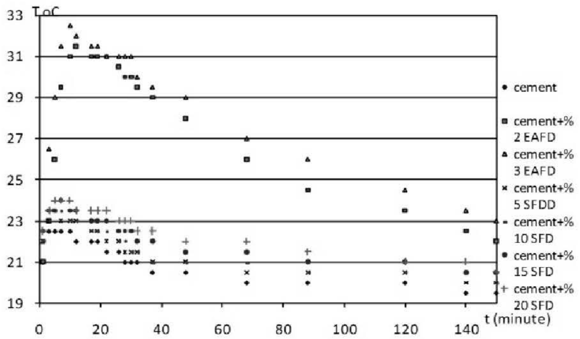

Fig. 4. Hydration heat of cement and its mixtures with EAFD and SFD dust

Fig 5 shows selected results of strength measurements of mixtures during 7–360 days period. Further experiments proved that compressive strength of cement + SFD dust mixtures is stabilized even in longer time intervals (more than 1 year). Obviously, this difference is the result of the presence of Zn in dust. The main composition of Zn is in the form of ZnO; this compound affects the hydration of Portland cement by postponing hardening of the mixtures. Moreover, it lowers the strength of the dust and cement mixtures [10]. This is due to the reaction of lime with zinc oxide which forms the low solubility Zinconates [10].

There are significant differences between the 2 groups (mixture of SFD dust – cement and mixture of EAF dust and cement). Differences are mainly in compressive strength and standard characteristics of cement such as hydration heat, setting times of the mortars and compressive strength. The main difference between these 2 kinds of dust (SFD dust and EAF dust) is the removal of alkaline compounds by soaking EAF dust in water. That is to say, removal of these compounds is the key to enhance the compressive strength and staying in the standard zone of cement.

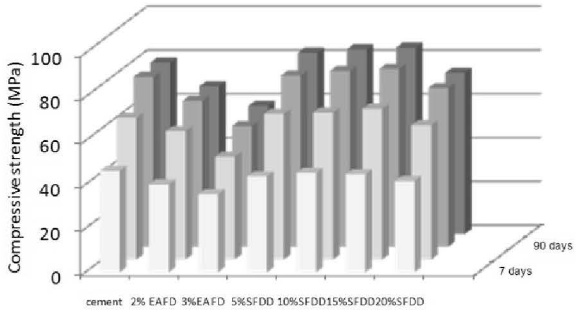

Fig. 5. Compressive Strength development of different mixtures of cement with EAFD and SFDD

Viscosity versus SFD dust content of cement is shown in Fig. 6. When very fine SFD dust fills up the space between cement particles, rheological properties of mixtures improve.

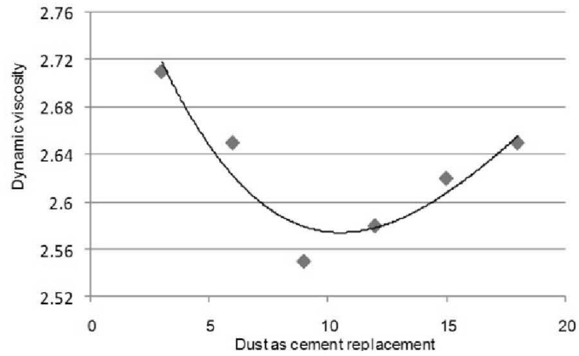

Fig. 6. Rheological properties of cement pastes with steel foundry dust

Results show that addition of SFD dust up to 15 wt. % to Portland cement not only does not cause any loss of strength but also in most cases, increases the compressive strength. Therefore, SFD dust could be regarded as an additive to the cement or as its partial replacement. The time dependence of the strength development of these mixtures depends on ZnO content and the kind of iron oxide in the dust [8,11].

The fracture surfaces (Fig. 7) of SFD dust-cement mixtures and Portland cement (Fig. 8) do not have noticeable difference.

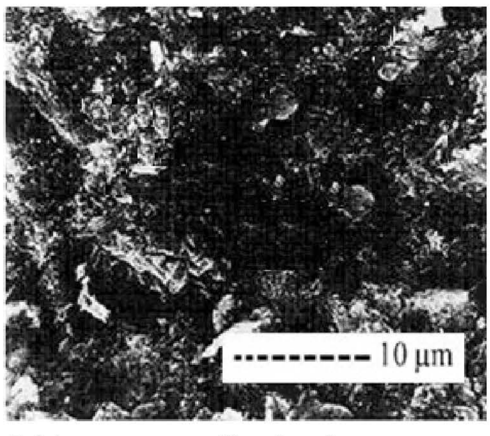

Fig. 7. Microstructure of hardened cement paste with 15% of SFD dust

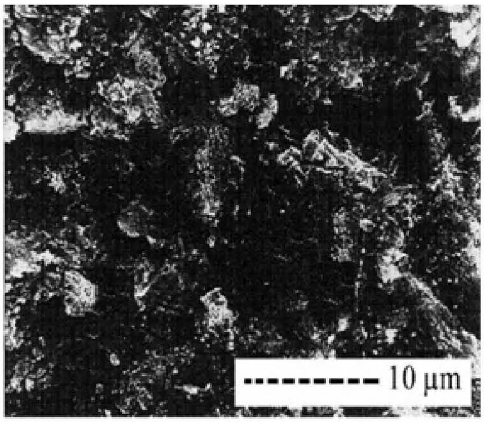

Fig. 8. Microstructure of hardened cement paste with 15% of SFD dust

Leaching tests indicate extremely low concentration of heavy metals in the leachates (with up to 20 wt. % SFD or EAF). As it is shown (Fig. 9) heavy metals content in the leachates are considerably below the nonhazardous leachates limits [12]. Therefore, our results agree well with the previous studies [4,5,7,8]. Leaching tests of the splits from hardened SFD dust + Portland cements have proved that the leachates are in the range of nonhazardous limits up to 20% dust containing 9-12% ZnO [12].

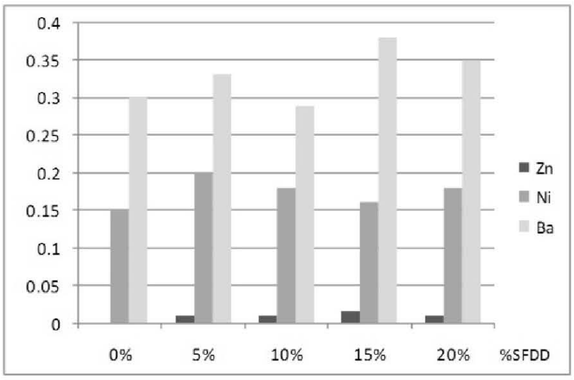

Fig. 9. Leachability of hardened cement paste with steel foundry dust (ZnO=13.8%)

SFD dust is similar to "silica fume", which is a flow dust that contains amorphous spherical particles of SiO_2 that have similar dimensions and morphology as SFD dust. Silica fume is used as an important additive to some kinds of cements [13]. The SFD dust and silica fume both behave in similar ways. These particles indicate their ability to fill up the gap between cement particles which are much bigger than their size (filler effect). They also participate in the hydration process during hardening of cement. Strength increase is due to hydration of cement with SFD particles, which is the result of the reaction of $Ca(OH)_2$ on the C–S–H phase.

Shorter final setting time of cement and SFDD mixtures is due to high specific surface of dust. Dust particles increase the nucleation of the C–S–H phase; they react with $Ca(OH)_2$ and on the C-S-H phase, and it causes strength increase. However detection of dust particles in mixtures is not possible. Fe_2O_3 and Fe_3O_4 do not react with $Ca(OH)_2$ but they speed up the nucleation of the C–S–H phase [8]. Therefore, dust becomes involved in the process of cement hydration. Development of strength virtue time also supports the above assumption. In many experiments, strength of these mixtures not only does not decrease but in many, the strength measurements have shown a relatively significant increase in the mixtures.

The SFD dust addition to cement for building materials up to 15% has favorable effects on building materials. The results will be published later. Hence, SFD dust is a useful replacement of cement and can be widely used like "silica fume".

4- Conclusions

The EAF dust consists of very fine particles mainly consisting of Fe oxides, alkaline composition and Zinc oxide. These particles are commonly smaller than 10 nm but the clusters can reach 500 nm. By comparing the differences between mixtures of EAF and SFD dust with cement and the composition of these 2 dusts, it is proved that the removal of alkaline compounds stabilizes the standard characteristics of cement, and so the SFD dust enhances the compressive strength of the cement paste. So, SFD dust has similar properties to very fine silicon dust. The results indicate that usage of EAF dust has novel properties that allow it to be used in building materials (concretes).

The mixtures of EAF dust + cements are largely affected by ZnO content of EAF dust. This is due to alternation in hydration of the mixtures and it reveals its effect in the time of hardening and the strength development.

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